TEMPERATURE EFFECTS IN FRESH PAPAYAS PROCESSED FOR SHIPMENT

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Bulletin 122
Hawaii Agricultural Experiment Station
University of Hawaii
April 1960

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INTRODUCTION

Fresh papayas intended for shipment to the mainland United States must be treated for the destruction of fruit flies with either vapor heat or fumigation. In the approved vapor heat treatment, fruits are subjected to heat until a fruit temperature (in center of fruit) of 117° F. is attained under 100 percent saturation. In the approved fumigation treatment, the fruits are subjected to ethylene dibromide (EDB) either in the unpacked condition or in packed and sealed condition ("prepacked" treatment). For unpacked papayas, the treatment requires an EDB dosage of ½ pound per 1,000 cubic feet for 2 hours at a minimum fruit temperature of 70° F. For fumigation of prepacked fruits, the required gas dosage is 1½ pounds per 1,000 cubic feet for the same period and temperature.

Subsequent to treating papayas with hot water at temperatures of 110° to 120° F. for 20 minutes to control storage decay (*1, 2, 3*), the fruit temperature may be as high as 100° F. or higher. Such hot water-treated fruits can be safely fumigated at an EDB dosage of ½ pound in the unpacked condition. When fumigated at a dosage of 1½ pounds, however, these "hot" fruits are injured (scalded) even in the prepacked condition. A scalded papaya is characterized by brown areas on the fruit surface. In addition to high temperature, scalding may be caused by low temperature and fumigation. The prepacked treatment is the preferred one because of its greater convenience over the unpacked treatment. One phase of the present study has been the determination of the temperature tolerance limit to the higher dosage of EDB in prepacked papayas and the development of safe methods to reduce the ambient fruit temperature to tolerant levels.

Improper cooling of fruits in the cartons readied for shipment and stored in the shipper's reefer for precooling purpose as well as improper cooling in the ship's reefer has been suspected of being at least one cause of the occasional arrival of papayas on the West Coast in an unmarketable condition. The heat-insulating capacity of the commercial papaya shipping carton was investigated as a possible cause of this dilemma. The effect of "sweating" (condensation of moisture on the fruit surface as a result of transferring fruits from low temperature storage to higher temperatures) on the degree of incidence of storage decay was also investigated.

INFLUENCE OF FRUIT TEMPERATURE ON FUMIGATION EFFECTS

Freshly harvested papayas (color turning to ¼–colored stages) from the fields of the Horticulture Department at the Waimanalo Experimental Farm[1] were used

[1]Fruits were also supplied by Sea View Farms, Honolulu, Hawaii.

in experiments to determine the effect of various fruit temperatures at the time of fumigation on tolerance to the treatment. The required fruit temperatures were obtained by dipping the fruits in hot water at a temperature of 120° F. for varying periods up to 20 minutes. The fruits were then packed in commercial cartons[2] and fumigated with EDB at a dosage of 1½ pounds per 1,000 cubic feet for 2 hours at room temperature. After fumigation, the cartons were stored in a reefer maintained at a temperature at 45° F. for 6 days to simulate shipping conditions to the mainland United States by surface transportation. The cartons were subsequently transferred to room temperature and the fruits were observed daily for injury as indicated by scalding. The results of the experiments are compiled in table 1.

TABLE 1. Relation of fruit temperature during fumigation to scalding in papayas treated with hot water at 120° F. for varying periods up to 20 minutes

Fruit temperature (° F.) during fumigation	Degree of scalding
76.5–77.0*	None
85.0–86.0	None
86.0–87.0	None
88.0–89.5	None
90.0–92.0	Slight
94.0–96.0	Moderate
97.0–98.0	Severe

*No hot water.

The tolerant temperature limit for fumigation of papayas seems to be approximately 90° F. (table 1). Fruits fumigated at fruit temperatures above this were scalded. That the scalding was due to the combined effect of high fruit temperature and fumigation and not to high temperature alone was indicated in other tests. No scalding occurred when hot water-treated fruits with initial temperatures as high as 104° F. were stored under similar conditions without fumigation.

The effect of hot water temperatures below 120° F., but within the effective range for storage decay control, on scald development in fumigated papayas was studied. The results are recorded in table 2.

TABLE 2. Effect of 20-minute exposures to hot water temperatures on fruit temperature and tolerance to fumigation

Hot water temperature (° F.)	Fruit temperature (° F.) during fumigation	Degree of scalding
No hot water	84– 84	None
116	97– 98	None to moderate
117	99–102	Moderate to severe
118	102–103	Severe
119	103–104	Severe
120	103–104	Severe

The data in table 2 again indicate that if the fruit temperature is high at the time of fumigation, the fruit is scalded. Of the temperatures used, 116° F. caused the least amount of scalding in spite of the high fruit temperature.

[2]All cartons and packing materials were supplied by Sea View Farms, Honolulu, Hawaii.

Using the hot water temperature of 116° F., the exposure time was varied in the next experiment (table 3).

TABLE 3. Effect of hot water temperature of 116° F. at varying exposures on fruit temperature and tolerance to fumigation

Exposure time (min.)	Fruit temperature (° F.) during fumigation	Degree of scalding
0	79–80	None
1	84–84	None
3	88–88	None
5	89–89	None
7	90–91	Slight
10	92–95	Slight
15	95–97	Slight
20	97–98	Slight

Fruits with temperatures above 90° F. were again scalded by the fumigation (table 3). This injury, however, was not in general as severe as that of the fruits treated with hot water at 120° F. (table 1).

COOLING HOT WATER-TREATED FRUITS

The necessity of reducing the fruit temperature after the hot water treatment to levels at least below 90° F. prior to fumigation is obvious from the above studies.

Cold water dip is the most rapid method of cooling papayas. Fruits dipped in hot water at 120° F. for 20 minutes were immediately transferred to water cooled to 46° F. by ice. After cooling for various periods, the fruits were packed and fumigated at a dosage of 1½ pounds for 2 hours at room temperature, then stored at 45° F. for 6 days, followed by storage at room temperature for observations. The results of a representative experiment are recorded in table 4.

TABLE 4. Effect of cooling papayas treated with hot water (120° F. for 20 minutes) with cold water (46° F.) prior to fumigation

Treatment	Fruit temperature (° F.) during fumigation	Degree of scalding	Decay percentage
Hot water, no cold water	92.0–94.5	Severe	63.6
Hot water, cold water 2 min.	83.0–84.0	Severe	63.6
Hot water, cold water 5 min.	80.0–82.0	Severe	81.8
Hot water, cold water 10 min.	74.5–75.0	Severe	72.7
Hot water, cold water 15 min.	70.5–71.0	Severe	81.8
No hot water, no cold water	70.0–70.5	None	90.9

A number of pertinent factors on the relationship between fruit temperature and tolerance to fumigation is revealed in the data in table 4. In the first place, hot water-treated fruits which were not cooled with cold water and in which the fruit temperature ranged above 90° F. were again scalded by the fumigation. In the second place, lowering the fruit temperature down to as low as approximately

70° F., by dipping in cold water for 2–15 minutes, did not improve the tolerance of the fruits for they were as severely scalded as the uncooled fruits. Moreover, fruits fumigated without hot water and cold water dips were not scalded. However, as expected, a very high percentage of storage decay resulted in these fruits. Furthermore, the seeming lack of decay control in the hot water-treated lots was caused by the scalded areas developing into decay lesions; that is, probably secondary infection set in. Thus, it is concluded that cold water (46° F.) is detrimental when used to lower the temperature of papayas treated with hot water at 120° F. for 20 minutes prior to fumigation.

Hot water-treated fruits were cooled with cold water and stored under simulated shipping conditions without fumigation. These fruits were not scalded. This indicated that the cold water treatment in itself was not harmful; when these cooled fruits were fumigated, however, they were severely scalded.

Attempts were made to cool hot water-treated papayas by storage in a reefer maintained at 45° F. prior to packing and fumigating. The results are given in table 5.

TABLE 5. Effect of cooling papayas treated with hot water (120° F. for 20 minutes) in air at 45° F. prior to fumigation

Treatment	Fruit temperature (° F.) during fumigation	Degree of scalding	Decay percentage
Hot water, no cooling	90.0–94.0	Severe	0.0
Hot water, cooled 10 min.	88.0–89.5	Severe	0.0
Hot water, cooled 30 min.	84.5–87.0	Severe	0.0
Hot water, cooled 60 min.	80.5–81.0	Severe	0.0
No hot water, no cooling	71.5–72.0	None	81.8

As in the case of cold water-cooled fruits, papayas cooled in the reefer at 45° F. did not tolerate the subsequent fumigation (table 5). The fruits were severely scalded even at fruit temperatures below 90° F. In this case, however, the scald apparently did not develop into secondary infections since no storage decay was evident in the hot water-treated lots.

In subsequent tests, fruits treated with hot water at 120° F. for 20 minutes were cooled in the reefer at 55° and 65° F. and at room temperature for varying periods to lower the fruit temperature below 90° F. before fumigation. Hot water-treated fruits were also cooled under tap water shower and in running tap water. In all cases, the fruits were scalded. In one experiment, the fruit temperature was lowered to 76° F. after 1 hour in running tap water. In another instance, the fruit temperature was lowered to 77° F. under tap water shower in 25 minutes. Even these were scalded by the fumigation treatment.

From the above tests, it seems that fruits treated with hot water at a constant temperature of 120° F. for 20 minutes do not tolerate the fumigation treatment even after being cooled prior to fumigation.

Since the hot water treatment at 116° F. for 20 minutes caused only slight scalding in fumigated fruits (tables 2, 3), attempts were made to eliminate this

TABLE 6. Reducing temperatures of fruits treated with hot water at 116° F. for 20 minutes prior to fumigation and subsequent effect on scalding

Method of reducing fruit temperature	Fruit temperature (° F.) during fumigation	Scald development
Reefer at 40° F. for 35 min.	84–80	None
Reefer at 45° F. for 45 min.	85–80	None
Reefer at 55° F. for 50 min.	80–81	None
Cold water (46° F.) for 7 min.	80–80	None
Cold water (46° F.) for 10 min.	76–75	None
Tap water shower for 20 min.	85–84	None
Running tap water for 15 min.	87–86	None
None	97–94	Slight

injury by lowering the fruit temperature prior to fumigation. A summary of these tests recorded in table 6 indicates that this can be easily effected by different cold treatments.

The most practical method of using the hot water treatment is to bring the temperature up to 120° F. and then immerse the fruit for 20 minutes without further heating. As long as the fruit temperature does not drop below 110° F. during the treatment period, the beneficial effect of the treatment on storage decay control is realized. In the next series of experiments, fruits were hot water-treated by this method and then cooled in various ways prior to fumigation. The results of one representative experiment recorded in table 7 show that fruits hot water-treated by this method can easily be made to tolerate the fumigation treatment by cooling them to temperatures below 90° F.

TABLE 7. Reducing temperatures of fruits treated with hot water at 120° to 112° F. for 20 minutes prior to fumigation and subsequent effect on scalding

Method of reducing fruit temperature	Fruit temperature (° F.) during fumigation	Scald development
Reefer at 45° F. for 40 min.	78–80	None
Reefer at 50° F. for 40 min.	84–86	None
Reefer at 55° F. for 50 min.	81–82	None
Cold water (46° F.) for 8 min.	77–78	None
Tap water shower for 20 min.	81–84	None
Running tap water for 15 min.	84–86	None
Running tap water for 20 min.	84–86	None
Overnight at room temperature (17½ hours)	75–76	None
None	95–97	Scald

INSULATING CAPACITY OF CARTONS

The corrugated cardboard of the commercial carton and shredded paper used in packing papayas afford effective insulation for the fruits. The insulating capacity of the standard sealed papaya carton (7″ × 11″ × 16″) was determined by measuring fruit and carton temperatures with fruit thermometers and thermocouples under storage conditions. The fruit temperature was determined by inserting the thermometer or thermocouple into the cavity of the fruit. The thermometer or the

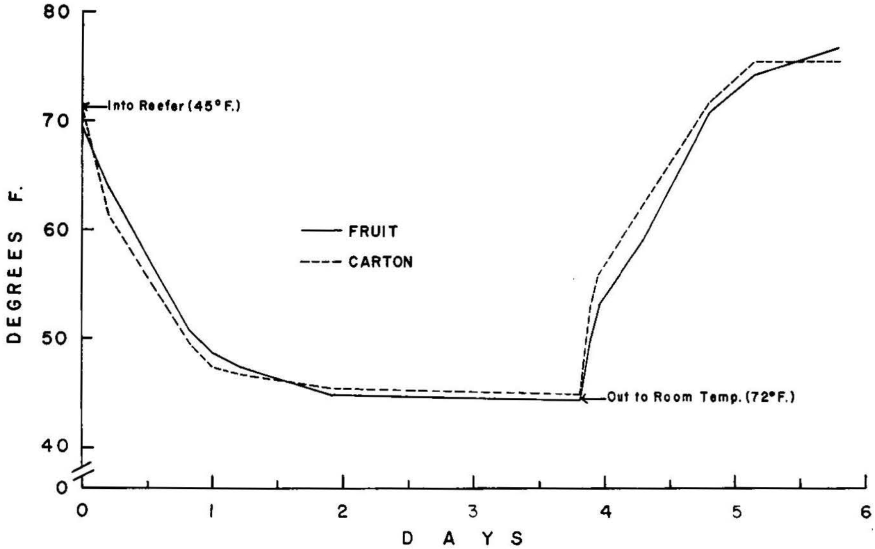

FIGURE 1. Fruit and carton temperatures of papayas in standard cartons in storage at 45° F. and room temperature.

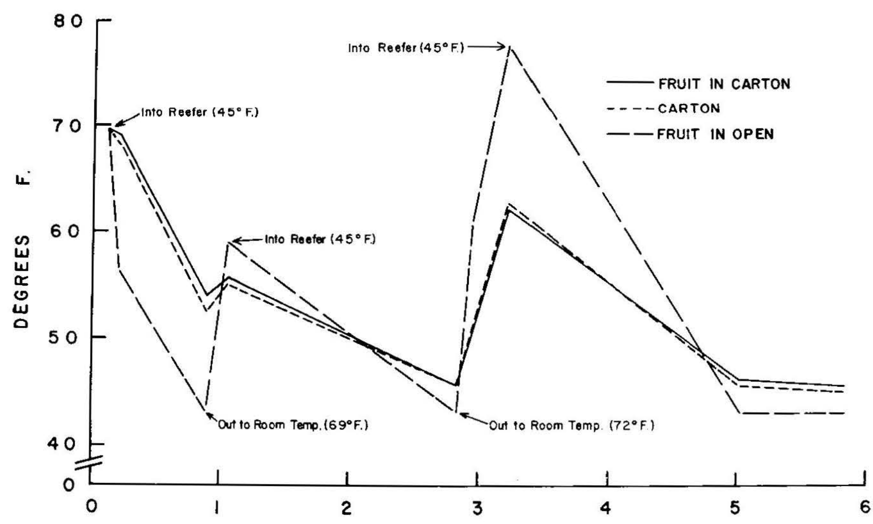

FIGURE 2. Fruit and carton temperatures of papayas in standard cartons stored alternately at 45° F. and room temperature as compared to temperature of fruits stored unpacked.

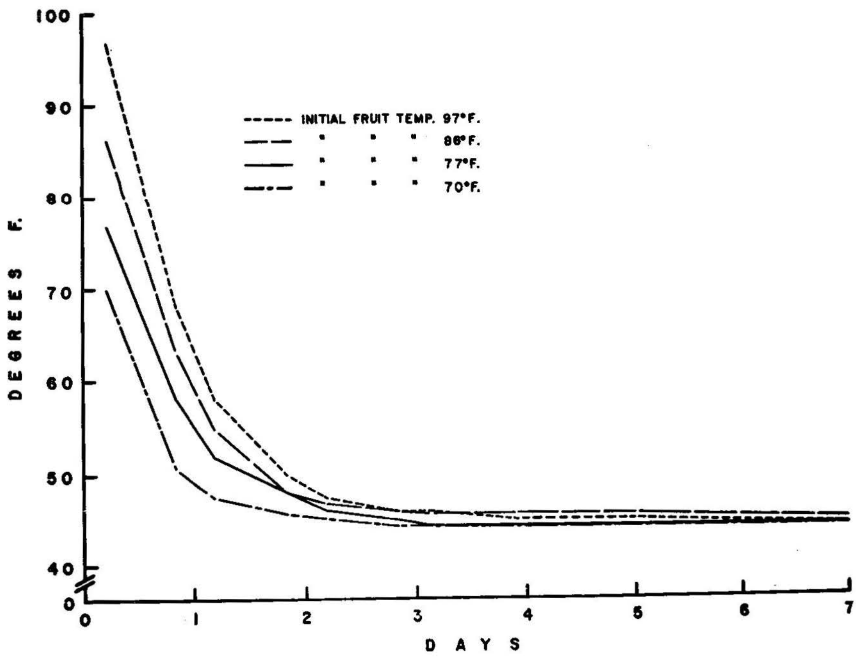

FIGURE 3. Effect of varying initial fruit temperatures on subsequent temperature fluctuation of papayas in standard cartons in storage at 45° F.

thermocouple inserted into the shredded paper packing measured the temperature of the carton.

The temperature curves in figure 1 indicate that in storage at 45° F. and at subsequent storage at room temperature, the carton temperature changed only slightly more rapidly than the fruit temperature. This is an indication of the insulating capacity of the carton. Approximately 46 hours were required for both the fruit and carton temperatures to drop to the level of the storage temperature (fig. 1).

The temperature fluctuations in fruits stored unpacked were compared with those of fruits in sealed cartons. Data from a test in which fruits were stored alternately at 45° F. and room temperature are graphically depicted in figure 2. Here again, the fruit and carton temperatures fluctuated to approximately the same degree. As expected, the temperature of the unpacked fruits fluctuated very much more rapidly than that of the packed fruits. At the end of approximately 17 hours in the initial storage period at 45° F., the temperature of the unpacked fruits was down to that of the storage medium, whereas the temperature of the packed fruits was down to only about 56° F. in the same period. Similar differences in temperatures between packed and unpacked fruits were observed in subsequent storage media. These results are additional indication of the insulating capacity of the cartons.

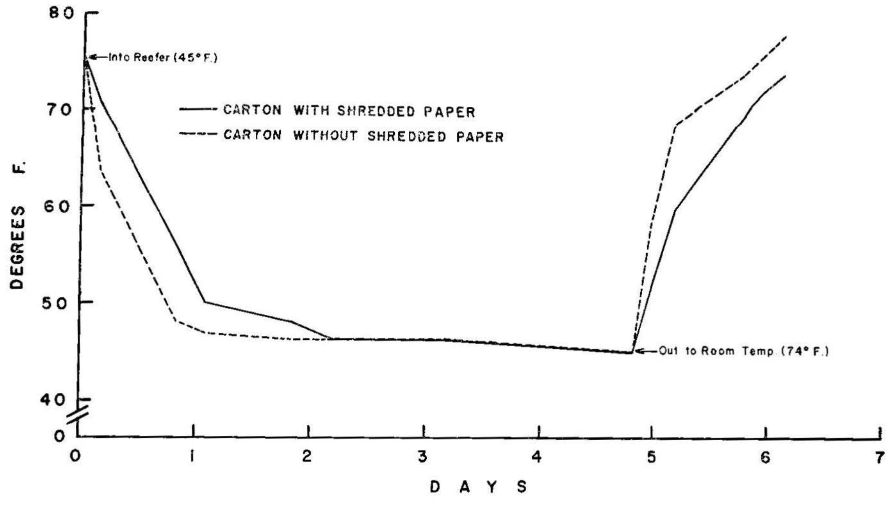

FIGURE 4. Effect of shredded paper on temperatures of papaya fruits in storage at 45° F. and room temperature.

The effect of initial fruit temperature on the time required for cooling to reefer temperature at 45° F. was determined. The varying initial temperatures were obtained by subjecting the fruits to hot water at 120° F. for different periods prior to packing. The results in figure 3 show the expected differences in cooling times of fruits as determined by their initial storage temperatures. Times required for the fruits to attain the storage temperature for fruits with initial temperatures of 70°, 77°, 86°, and 97° F. were approximately as follows: 44, 63, 89, and 168 hours, respectively (fig. 3). These results are further indication of the insulating capacity of the carton.

The insulating capacity of the shredded paper that is used for keeping the fruits in place in the commercial carton was next investigated. This was done by packing the fruits in cartons with and without the packing material and subjecting them to reefer and room temperatures. That the shredded paper as employed in the commercial pack affords excellent insulation is shown in figure 4 in which is indicated the more rapid response to external temperatures by the fruits packed in the carton without the packing material as compared to those in the normal carton.

In the next series of experiments, the insulating capacity of a new carton was compared with that of the standard carton. The new carton (7″ × 12″ × 12″) is slightly smaller than the standard carton. It has perforations, the diameter of which is equivalent to that of the mesh in mosquito screen. These perforations are in conformity with the quarantine regulations. There are 240 perforations distributed among the four walls of the carton. These perforations are imperfect in that they are merely punched in from the outside without being completely cut

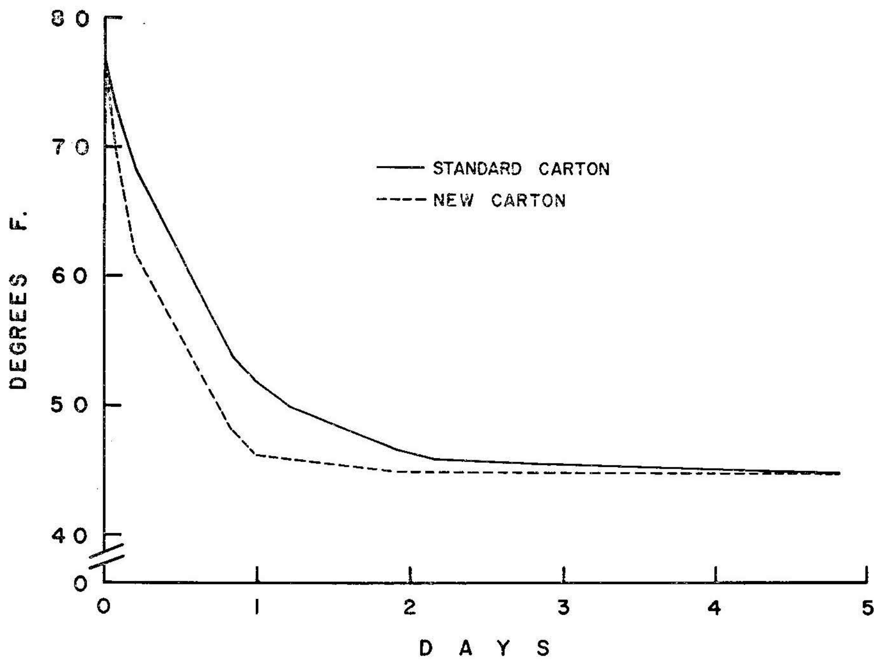

FIGURE 5. Fruit temperatures of papayas in standard carton and new carton in storage at 45° F.

through and thus are practically sealed back by the flared corrugated cardboard. The cartons are designed for nine fruits for a net fruit weight per carton of approximately 10 pounds. Instead of shredded paper, cardboard dividers[3] are used. A quiltlike padding[4] placed at the bottom of the carton and on the top of the fruits is used to keep the fruits in place in the carton.

The results of a typical experiment as illustrated in figure 5 show the advantage of the new carton over the standard carton. For fruits in storage at 45° F., the temperature change of fruits in the new carton (fig. 5) is very similar to that of fruits in the standard carton without the shredded paper (fig. 4). Since it is doubtful that the imperfect perforations on the new carton have any effect on the temperature change in the carton, it appears that the shredded paper is the critical material that increases the insulating capacity of the carton. As in the case of the standard carton (figs. 1, 2), it was demonstrated in other tests that the temperature of the fruit in the new carton fluctuated to the same degree as the carton temperature.

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[3], [4] The use of cardboard dividers and quiltlike padding instead of shredded paper in the prepacked fumigation treatment is not as yet approved. These materials may, however, be used for fruits fumigated in the unpacked condition or for fruits treated with vapor heat.

EFFECT OF "SWEATING" ON DECAY INCIDENCE

Fruits were treated variously, stored in the cold for various periods, removed to room temperature, allowed to "sweat" in the unopened standard carton for varying periods, then placed back in the cold storage to conclude the simulated shipping storage period after which they were stored at room temperature and observed until overripe. A typical experiment produced the results tabulated in table 8.

TABLE 8. Decay percentage of fruits variously treated, stored at 45° F. for 2 days, allowed to "sweat" at room temperature, and stored again at 45° F. for an additional 4 days before removal to room temperature

Treatment	"Sweating" period at room temperature (hr.)	Temperature change during "sweating" period (° F.)	Decay percentage at overripe stage
None	4	49–56	83.3
None	0	49–48	83.3
Hot water*	4	48–56	25.0
Hot water*	0	49–48	25.0
EDB†	4	47–54	83.3
EDB†	0	48–47	83.3
Hot water, cooled‡, EDB	4	49–57	25.0
Hot water, cooled‡, EDB	0	49–48	25.0

*120°–112° F. for 20 minutes.
†1½ pounds per 1,000 cubic feet for 2 hours at room temperature.
‡Overnight at room temperature.

That "sweating" does not affect the degree of decay incidence is clearly indicated in table 8. This is so, regardless of the treatments involved. This is further manifested in the composite data for all "sweating" tests tabulated in table 9.

TABLE 9. Effect of "sweating" on decay incidence. (Composite data of all tests.)

Treatment	Total number of fruits	Number of fruits decayed	Percent fruits decayed
"Sweat"	329	224	68.1
No "sweat"	307	209	68.1

DISCUSSION AND CONCLUSION

Results have been presented which indicated that the maximum fruit temperature that the prepacked papaya can tolerate when fumigated with EDB at 1½ pounds per 1,000 cubic feet for 2 hours at room temperature is probably just below 90° F. Not only the temperature of the fruit as a result of the hot water treatment, but also the temperature of the hot water bath during a 20-minute treatment determine whether the treated fruits can tolerate the subsequent fumigation treatment. In general, it appears that hot water temperatures above 116° F. are detrimental even if the fruits are cooled to temperatures below 90° F. prior to fumigation.

Results of attempts to reduce the fruit temperature of hot water-treated papayas to tolerant levels indicated that constant hot water bath temperatures above 116° F. for a 20-minute dip treatment are detrimental. These treatments caused scalding of fruits in which the temperature was reduced to levels below 90° F. prior to fumigation. Treatments in which the hot water temperature was maintained at 116° F. or allowed to drop from 120° to 112° F. during the 20-minute immersion period did not cause scalding, provided the fruits were cooled to temperatures below 90° F. prior to fumigation. Cooling was effected by storage in the reefer and at room temperature, immersion in cold water and running tap water, and by tap water shower.

These studies indicate that injuries of commercially fumigated papayas could easily be caused by either excessively high hot water temperatures or inadequate cooling prior to fumigation. Constant hot water temperatures up to 120° F. for an immersion period of 20 minutes are not injurious to uncooled fruits fumigated with EDB at a dosage of ½ pound per 1,000 cubic feet for 2 hours at room temperature. However, when fumigation is at the dosage of 1½ pounds required for prepacked fruits, constant hot water temperatures above 116° F. result in injury even if fruits are cooled prior to fumigation.

The insulating capacity of the standard papaya carton was clearly demonstrated in tests in which temperature changes in the fruits in storage were observed. It was also demonstrated that the shredded paper used in the commercial pack contributes significantly to the insulating capacity of the carton. In a practically empty reefer maintained at a temperature of 45° F. with good air circulation, the experimental papayas in the commercial carton required approximately 2 days for their temperature to drop to that of the reefer. In a large commercial shipment in the shipper's reefer and in the ship's reefer, one would therefore expect a much slower drop in fruit temperature. This may be one cause of the reported poor arrival condition of the papayas on the West Coast.

Experiments with a new carton in which shredded paper was replaced by dividers and padding indicated the wisdom of eliminating the shredded paper as a packing material. Temperatures of fruits packed in the new cartons and in standard cartons without the shredded paper dropped to that of the reefer in about half the time required for fruits packed in the standard cartons with shredded paper.

Some shippers are of the opinion that papayas allowed to "sweat" in transit to the docks and on the docks prior to loading into the ship's reefer have higher rates of storage decay than fruits not allowed to "sweat" and therefore do not favor storing the fruits in the cold just prior to shipment. Experimental papayas allowed to "sweat" at room temperature after various treatments and storage did not affect the rate of decay incidence. This opinion therefore seems unfounded.

RECOMMENDATIONS

The following recommendations as developed from the studies reported here are for prepacked papayas fumigated with EDB at a dosage of 1½ pounds per 1,000 cubic feet for 2 hours at room temperature after the hot water treatment.

1. If constant temperature is to be maintained in the hot water treatment, it should not exceed 116° F. for the duration of the 20-minute dipping period.

2. A more practical method is to allow the temperature of the hot water to drop from 120° F. to below 116° F., but not below 110° F. during the 20-minute dipping period. This is done by removing the heat when the water temperature reaches 120° F. and immersing the fruits.

3. The temperature of the hot water-treated fruits should be reduced to at least below 90° F. with a tap water shower before fumigation. The fruits may also be cooled overnight at room temperature. The other methods of cooling may be less practical.

4. If cardboard dividers and quiltlike padding are approved as packing materials, these should be used instead of shredded paper.

5. If papayas must be held prior to loading on board ship, they should be kept refrigerated, since "sweating" does not affect the rate of storage decay.

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